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Invention: APPARATUS AND METHOD FOR POSITIONING HEAD AT TARGET POSITION ON DISK

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This is a:

☐ Provisional Application

☒ Regular Utility Application

☐ Continuing Application
☐ The contents of the parent are incorporated by reference

☐ PCT National Phase Application

☐ Design Application

☐ Reissue Application

☐ Plant Application

☐ Substitute Specification
Sub. Spec Filed ____________
in App. No. ______/______

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SPECIFICATION

TITLE OF THE INVENTION

APPARATUS AND METHOD FOR POSITIONING HEAD AT TARGET POSITION ON DISK

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2002-380276, filed December 27, 2002, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a disk drive that uses a head to read and write data from and to a disk, and in particular, to a disk drive that sets an offset between a track position specified by a command from a host and a target position at which the head is to be actually positioned, as well as a head positioning method used for this disk drive.

2. Description of the Related Art

A hard disk drive is well known as a disk drive that uses disks (disk media) as recording media. In general, a plurality of concentric servo tracks are arranged on a recording surface of a disk. The pitch of the servo tracks on the disk is fixed. Servo information is pre-written in each servo track discretely at equal intervals in the circumferential direction of the disk. The servo information

pre-written in the disk is called embedded servo. The servo information is a kind of positional information, also called a servo pattern, and contains address code and burst signals. The address code contains a cylinder code (cylinder number). The cylinder code indicates a cylinder position on the disk at which the corresponding servo information is written. The burst signal is also called a position error signal, and it indicates information (position error) on the position of the head relative to the cylinder (servo track) in which the corresponding servo information is written. The cylinder code in the servo information is a value that varies with the consecutive servo tracks (in general, the respective servo tracks have different values).

If a host utilizing the hard disk drive provides a read/write command to the drive, the position of a target track on the disk specified by this command is calculated. Then, head positioning control is carried out on the basis of the servo information read by the head. This control allows the head to be positioned at the target position (in the radial direction of the disk). In this state, the head reads or writes data from or to the disk. In this case, the tracks in which the head writes data coincide with the servo tracks. The pitch of the tracks (track pitch) is fixed.

The heads of recent hard disk drives are mainly of a composite type. The composite head is composed of a read head (read element) and a write head (write element) separately formed on the same slider. With a hard disk drive comprising such a composite head, the signal to noise ratio of a read signal (reproduction signal) is degraded if the head has a large azimuth angle. This is because crosstalk may occur, in which data recorded in a track on the disk is deleted by writing data in adjacent tracks.

Thus, techniques have hitherto been proposed which suppress the adverse effects of crosstalk. For example, Jpn. Pat. Appln. KOKAI Publication No. 10-255201 describes a technique of dividing the recording surface on the disk into areas with a large azimuth angle and areas with a small azimuth angle. The technique (hereinafter referred to as the prior art) described in this publication arranges servo tracks in each area, the tracks having a track pitch unique to that area. Specifically, in the prior art, servo information is written using different track pitches for the areas with the large azimuth angle and for the areas with the small azimuth angle.

Thus, in the prior art, in order to suppress the adverse effects of crosstalk resulting from the large azimuth angle of the head, it is necessary to write servo information using different track pitches for

the respective areas into which the recording surface has been divided on the basis of a difference in azimuth angle. However, the length (known as the head width) of the head in the radial direction of the disk varies with the head. Crosstalk may also occur if the width (write width) over which data is actually written varies owing to the variation in head width. In this case, different track pitches must be used to write servo information in the respective areas on the disk into which the recording surface is divided, also taking the variation in head width into account.

BRIEF SUMMARY OF THE INVENTION

According to an embodiment of the present invention, there is provided a disk drive comprising a disk having a recording surface on which a plurality of concentric tracks are arranged at a fixed pitch, wherein data is read from and written to the disk by a head arranged in association with the recording surface of the disk. The disk drive comprises calculating means, determining means, and executing means. The calculating means calculates a first offset value on the basis of the position of a first target track specified by a command from a host, the first offset value reflecting a track pitch which enables adverse effects of crosstalk to be suppressed. The first offset value indicates an offset of a target position at which the head is to be actually

positioned from a predetermined position on the first target track in a radial direction of the disk. The determining means determines a second target track, to which the target position belongs, and a second offset value on the basis of the position of the first target track and the first offset value calculated by the calculating means. The second offset value indicates an offset of the target position from a predetermined position on the second target track in the radial direction of the disk. The executing means executes control to position the head at the target position on the second target track on the basis of the second target track position and second offset value each determined by the determining means.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention, and together with the general description given above and the detailed description of the embodiments given below, serve to explain the principles of the invention.

FIG. 1 is a diagram showing the configuration of a hard disk drive according to an embodiment of the present invention;

FIG. 2A is a view showing the format of a recording surface H_i (i=0, 1) of a disk 11;

FIG. 2B is a diagram showing that cylinder codes

with different values are written in consecutive servo tracks on the disk 11 at a fixed pitch;

FIGS. 3A and 3B are views showing the relationship between a set of areas A_1 to A_n on recording surfaces H_0 and H_1 of the disk 11 and a set of offset values ΔO_1 to ΔO_n for the respective areas A_1 to A_n;

FIG. 4 is a diagram showing an example of the structure of data in an offset table 222;

FIG. 5 is a diagram showing an example of the positional relationship between a first target track TT_1 and a second target track TT_2 if the first target track TT_1 is each of the consecutive servo tracks T_{jk} on the disk 11;

FIG. 6 is a flow chart showing an operational procedure used when a command is executed;

FIG. 7 is a diagram showing an example of the relationship between both the first target track TT_1 ($=T_{jk}$) and offsets O_j and ΔO_j and both the second target track TT_2 and an offset $\Delta O_j'$;

FIGS. 8A and 8B are diagrams showing that unique offset values are stored in FROMs 22 provided in respective HDDs having different data track pitches (track density);

FIGS. 9A and 9B are flow charts showing the procedure of a process for determining the offsets O_j and ΔO_j for each area A_j;

FIG. 10A is a diagram showing that a head 12_{-i}

is positioned at a predetermined position on the track T_{jk};

FIG. 10B is a diagram showing that the head 12_{-i} is offset from the predetermined position on the track T_{jk} in a radially outside direction of the disk; and

FIG. 10C is a diagram showing that the head 12_{-i} is offset from the predetermined position on the track T_{jk} in a radially inward direction of the disk.

DETAILED DESCRIPTION OF THE INVENTION

With reference to the drawings, description will be given of an embodiment in which the present invention is applied to a hard disk drive. FIG. 1 is a block diagram showing the configuration of a hard disk drive (hereinafter referred to as an HDD) according to an embodiment of the present invention. In FIG. 1, a disk (magnetic disk medium) 11 has two disk surfaces including a top and bottom surfaces. At least one of the two disk surfaces of the disk 11, e.g. both disk surfaces constitute recording surfaces H_0 and H_1 on which data is magnetically recorded. Heads (magnetic heads) 12_{-0} and 12_{-1} are arranged in association with the recording surfaces H0 and H1, respectively. The head 12_{-i} (i=0, 1) is caused to float over the disk 11 by rotation of the disk 11 while the HDD is in operation. The head 12_{-i} is used to read data from the recording surface H_i of the disk 11 (data recording) and to write data to the recording

surface H_i of the disk 11 (data reproduction). The head 12_{-i} is of a composite type in which a read head 121 and a write head 122 are separately formed on the same slider. The read head 121 is, for example, a magneto resistive head (MR head) composed of a magneto resistive (MR) element. The write head 122 is, for example, an inductive head composed of an inductive thin-film element. In the arrangement shown in FIG. 1, the HDD is assumed to comprise a single disk 11. However, the HDD may comprise a plurality of disks 11 stacked.

FIG. 2A shows the format of the recording surface H_i (i=0, 1) of the disk 11. As shown in this figure, a plurality of servo areas 110 are arranged on the recording surface Hi of the disk 11 discretely at equal intervals in the circumferential direction of the disk 11 and radially in the radial direction of the disk 11. The area between the adjacent servo areas 110 on the recording surface H_i is used for user data. A plurality of data sectors are arranged in the user data area. A plurality of concentric servo tracks 111 are arranged on the recording surface H_i of the disk 11. The pitch (servo track pitch) of the servo tracks 111 is fixed. Servo information is pre-written in each servo area 110 for each servo track 111. Each servo information item contains cylinder code (cylinder number) and burst signals.

The cylinder code and the burst signals are positional information required to position the head 12_{-i} at a target position on a target track. In this case, the cylinder code in the respective servo information items written in the servo area 110 for the respective servo tracks 111 are different values CYL (in general, different values).

Referring back to FIG. 1, the disk 11 is rotated at a high speed by a spindle motor (hereinafter referred to as an "SPM") 13. The head 12_{-i} is attached to the tip of an actuator (carriage) 14. The head 12-i moves in the radial direction of the disk 11 as the actuator 14 moves rotatively. Thus, the head 12_{-i} is positioned on a target track. The actuator 14 includes a voice coil motor (hereinafter referred to as a VCM) 15 serving as a driving source for the actuator 14. The SPM 13 and the VCM 15 are driven by driving currents independently supplied by a driver IC 16. The driver IC 16 is a motor driver composed of one chip. A CPU 21 determines the amount of control required to determine the driving currents supplied by the driver IC 16 to the SPM 13 and the VCM 15, respectively.

The head 12_{-i} is connected to a head IC (head amplifier circuit) 17. The head IC 17 includes a read amplifier (not shown) that amplifies a read signal read by the head 12_{-i} and a write amplifier (not

shown) that converts write data into a write current. A head IC 23 is connected to a read/write IC (read/write channel) 18. The read/write IC 18 is a signal processing device that executes various signal processes. These signal processes include a process of subjecting a read signal to an analog-to-digital (A/D) conversion, a process of encoding write data, and a process of decoding digitalized read data. The read/write IC 18 also has a function of pulsing (binarizing) a read signal into a read pulse signal and a function of extracting burst signals (in this case, burst signals A, B, C, and D) from servo information in accordance with a timing signal (burst timing signal) from a gate array 19. The burst signals are transmitted to the CPU 21, which uses them for positioning control (track following control) to settle the head 12_{-i} at a target position on a target track.

The gate array 19 has a function of generating various timing signals including a burst timing signal, from a read pulse signal outputted by the read/write IC 18 and a function of extracting cylinder code from servo information. The cylinder code is used for seek control to move the head 12_{-i} to the target track. A disk controller (hereinafter referred to as an "HDC") 20 is connected to a host (host system) utilizing the HDD. The host is digital

electronic equipment represented by a personal computer. The HDC 20 processes read data decoded by the read/write IC 21 in accordance with a control signal from the gate array 19 to generate data to be transmitted to the host. The HDC 20 also transfers write data transferred by the host, to the read/write IC 18 in accordance with a control signal from the gate array 19.

The CPU 21 is a main controller for the HDD. The CPU 21 contains an FROM (Flash Read Only Memory) 22 and a RAM (Random Access Memory) 23. The FROM 22 is a rewritable nonvolatile memory. The FROM 22 pre-stores a control program 221 to be executed by the CPU 17. The control program 221 contains a process routine for determining a target position at which the head 12_{-i} is to be actually positioned, on the basis of positional information on a target track specified by a command from the host. The target position is determined taking the azimuth angle of the head 12_{-i} or the like into account. The FROM 22 also pre-stores an offset table 222, described later. A part of the entire area of the RAM 23 is used by the CPU 21 as a work area.

The offset table 222 indicates the relationship between concentric areas A_j (j= 1 to n) (see FIGS. 3A and 3B) on the recording surfaces H_0 and H_1 of the disk 11 and both offset values O_j and ΔO_j.

The recording surfaces H_0 and H_1 are divided into the areas A_j on the basis of the azimuth angle of each position of the head 12_{-i} in the radial direction of the disk. A plurality of servo tracks 111 are arranged in each area A_j. Here, the offset value (fourth offset value) O_j will be described. First, it is assumed that a leading track T_{j0} in the area A_j is a target track TT_1. The target track TT_1 (hereinafter referred to as a first target track TT_1) is specified by a read/write command from the host. In the present embodiment, a target position (the position in the radial direction of the disk 11) TP at which the head 12_{-i} is to be actually positioned does not always coincide with a predetermined position on the target track TT_1. If a track T_{j0} is assumed to be the track TT_1, the offset value O_j indicates the offset (for example, in the radially inward direction of the disk 11) of the target position TP from the predetermined position on the target track TT_1 (= track T_{j0}). A track on the disk 11 to which a target position (TP) belongs is called a second target track TT_2. The predetermined position varies between a data read and a data write because the head 12_{-i} is of the composite type. However, for simplification of description, the predetermined position is assumed to be on a center line in the target track TT_1.

The offset value (third offset value) ΔO_j

indicates the difference (pitch difference) between a servo track pitch STP and a data track pitch DTP. The data track pitch DTP enables the adverse effects of crosstalk to be suppressed. The DTP and the STP have the relationship expressed by the following equation:

$$DTP = STP + \Delta O_j \qquad (1)$$

In the prior art, the data track pitch DTP is equal to the servo track pitch STP. That is, $\Delta O_j=0$. In this case, the target position TP coincides with the predetermined position on the target track TT_1. However, when the data track pitch DTP is equal to the servo track pitch STP, with some HDDs, the adverse effects of crosstalk become more significant. Such HDDs are classified into two types. A first type includes HDDs in which the head 12_{-i} has an azimuth angle varying markedly depending on the position on the disk in its radial direction. With the first type of HDD, owing to the varying azimuth angle of the head 12_{-i}, the width (write width) over which data is actually written by the head 12_{-i} also varies depending on the position on the disk in its radial direction. This is equivalent to the head width of the head 12_{-i} varying depending on the position on the disk in its radial direction. A second type includes HDDs in which the heads 12_{-0} and 12_{-1}, corresponding to the recording surfaces H_0 and H_1, respectively, of

the disk 11, have greatly different head widths (which depend on the physical shapes of the heads). Thus, in the present embodiment, for each area A_j, a unique data track pitch DTP (DTP≥STP) is set which enables the adverse effects of crosstalk to be suppressed. Specifically, a unique offset value ΔO_j is set for each area A_j.

The numbers of servo tracks 111 arranged in areas A_1 to A_{j-1} are assumed to be N_1 to N_{j-1}, respectively. The offset value O_j can be calculated in accordance with the following equation:

$$O_j = O_{j-1} + \Delta O_{j-1}(N_{j-1} - 1/2) + \Delta O_j/2 \quad (2)$$

Specifically, the offset value O_j can be calculated from O_{j-1}, ΔO_{j-1}, and ΔO_j, as well as the number of tracks N_1 to N_{j-1}. In this case, $O_1 = \Delta O_1/2$.

Alternatively, the offset value O_j can be calculated using the following equation:

$$\begin{aligned} O_j &= O_{j-1} + \Delta O_{j-1}(N_{j-1} - 1/2) + \Delta O_j/2 \\ &= \Delta O_1 * N_1 + \Delta O_2 * N_2 + \cdots + \Delta O_{j-1} * N_{j-1} + \Delta O_j \\ &= \Sigma \Delta O_p * N_p + \Delta O_j \quad (3) \end{aligned}$$

Here, $\Sigma \Delta O_p * N_p$ represents the sum of $\Delta O_p * N_p$ for p=1 to j-1. As is apparent from Equation (3), the offset value O_j can also be calculated from the offset values ΔO_1 to ΔO_j and the number of tracks N_1 to N_{j-1}. Accordingly, if the time required to calculate the offset value O_j does not matter, information on the offset value O_j need not

necessarily be stored in an entry E_j in the offset table 222.

It is assumed that the k+1-th track T_{jk} in the area A_j is the first target track TT_1. In this case, the offset of the target position TP at which the head 12_{-i} is to be actually positioned, from the predetermined position on the target track TT_1 (=track T_{jk}) is expressed by $O_j+k(STP+\Delta O_j)=O_j+k*DTP$.

FIGS. 3A and 3B show the relationship between a set of the areas A_1 to A_n on the recording surfaces H_0 and H_1 of the disk 11 and a set of the offset values ΔO_1 to ΔO_n for the respective areas A_1 to A_n. The offset values ΔO_1 to ΔO_n are determined taking into account a difference in head width between the head 12_{-0} and the head 12_{-1} corresponding to the recording surfaces H_0 and H_1, respectively.

FIG. 4 shows an example of the structure of data in the offset table 222. As shown in this figure, each entry E_j (j=1 to n) in the offset table 222 stores track position information indicative of a leading track T_{j0} of the servo tracks 111 contained in the area A_j, as well as the offset values O_j and ΔO_j. Here, it is assumed that the first target track TT_1 is the track T_{jk}, $T_{j0} \leq TT_1 < T_{(j+1)0}$, and the track TT_1 is contained in the area A_j. In this case, with reference to the entry E_j in the offset table 222, it is possible to obtain the offset values O_j and ΔO_j

required to determine the offset of the target position TP at which the head 12_{-i} is to be actually positioned, from the (predetermined position on the) first target track TT_1.

FIG. 5 shows an example of the positional relationship between the first target track TT_1 ($=T_{jk}$) and a second target track TT_2 if the first target track TT_1 is each of the consecutive servo tracks T_{jk} on the disk 11. In the example in FIG. 5, for the convenience of drawing, it is assumed that four tracks are contained in each of the areas A_1, A_2, and A_3.

The CPU 21 in FIG. 1 controls each section of the HDD in accordance with the control program 221 stored in the FROM 22. For example, CPU 21 executes seek control to move the head 12_{-i} to the second target track TT_2 on the disk 11. The second target track TT_2 is determined on the basis of the first target track TT_1 and the offset values O_j and ΔO_j. Specifically, the second target track TT_2 is obtained by correcting the first target track TT_1 on the basis of the offset values O_j and ΔO_j; the head 12_{-i} is to be actually moved to the second target track TT_2. The CPU 21 also executes positioning control to the position the head 12_{-i} moved to the second target track TT_2, at the target position TP on the target track TT_2. The value $\Delta O_j'$ for the offset of the target position TP from the predetermined position on the second target track

TT_2 is determined on the basis of the first target track TT_1 and the offset values O_j and ΔO_j. The CPU 21 also uses the HDC 20 to execute read/write control in accordance with a read/write command from the host.

Now, with reference to the flow chart in FIG. 6, description will be given of execution of a read/write command in the HDD shown in FIG. 1, taking by way of example the case in which a write command from the host is executed. It is assumed that the host provides a write command to the HDD shown in FIG. 1. The write command is received by the HDC 20, which then passes the command to the CPU 21. If a read command or a write command has been delivered by the HDC 20, the CPU 21 calculates the position of the first target track TT1 specified by this command (step S1). Normally, a read/write command from the host specifies a disk address using a logic address (logic block address). Thus, to access the disk 11, it is necessary in step S1 to execute a calculation process to convert the logic address into a physical address representative of the first target track TT_1. Here, it is assumed that the first target track TT_1 is the track T_{jk}.

Once the CPU 21 identifies the position of the first target track TT_1 (step S2), it identifies the area A_j on the disk 11 to which the target track TT_1 ($=T_{jk}$) belongs (step S2). The area A_j is one of the

areas A_1 to A_n (see FIGS. 3A and 3B) into which the recording surface H_0 and H_1 are divided. Then, the CPU 21 references the entry E_j in the offset table 222 which corresponds to the area A_j identified in step S2 (step S3). Then, the CPU 21 reads the offset values O_j and ΔO_j stored in the referenced entry E_j (step S4). On the basis of the first target track TT_1 ($=T_{jk}$) and the offset values O_j and ΔO_j read in step S4, the CPU 21 calculates the value of the offset (first offset value) $\{O_j+k(STP+\Delta O_j)$ of the target position on the second target track TT_2 from a predetermined position on the first target track TT1 (Step S5). This offset value $\{O_j+k(STP+\Delta O_j)$ reflects a data track pitch that enables the adverse effects of crosstalk to be suppressed.

Then, on the basis of the target track TT_1 ($=T_{jk}$) and the offset value $\{O_j+k(STP+\Delta O_j)$, CPU 21 determines the position of the second target track TT_2 and the offset value (second offset value) $\Delta O_j'$ (step S6). As described previously, the offset value O_j can also be calculated in accordance with Equation (3) on the basis of the offset value ΔO_1 to ΔO_j. Therefore, the position of the second target track TT_2 and the offset value $\Delta O_j'$ can be determined from the first target track TT_1 (T_{jk}) and the offset values ΔO_1 to ΔO_j.

As described previously, the head 12_{-i} is to

be actually moved to the second target track TT_2. Specifically, the target position TP (at which the head 12_{-j} is positioned) that is offset from the predetermined position on the leading track T_{j0} in the area A_j by the offset value $\{O_j+k(STP+\Delta O_j)$ belongs to the second target track TT_2 (servo track 111). On the other hand, the offset value ΔO_j' indicates the offset of the target position TP on the second target track TT_2 from predetermined position on the target track TT_2. FIG. 7 shows an example of the relationship between both the first track TT_1 ($=T_{jk}$) and offsets O_j and ΔO_j and both the second target track TT_2 and an offset ΔO_j'.

Then, the CPU 21 executes seek control to move the head 12_{-i} to the target track TT_2 determined in step S6 (step S7). This seek control is executed on the basis of a cylinder code extracted from the gate array 19. When the head 12_{-j} is moved to the second target track TT_2, the CPU 21 executes positioning control (tracking control) to position (settle) the head 12_{-i} at the target position TP on the target track TT_2 (step S8). This positioning control is based on burst signals extracted by the read/write IC 18. The target position TP at which the head 12_{-i} is to be positioned in this positioning control is offset from the predetermined position on the second target track TT_2 in the radial direction of the disk 11 by

the offset value $\Delta O_j'$. When the head 12_{-i} is positioned within a predetermined error range from the target position TP (in this case, the target position for a write) on the second target track TT_2, the CPU 21 proceeds to step S9. In step S9, the CPU 21 causes the head 12_{-i} to execute a read/write (in this case, a write).

Thus, in the present embodiment, the target position TP at which the head 12_{-i} is to be positioned is determined to be a position on the target track TT_2 instead of the predetermined position on the first target track TT1 specified by a command from the host. The position on the second target track TT_2 is offset from the predetermined position on the first target track TT_1 in the radial direction of the disk 11 by the offset value (first offset value) $\{O_j+k(STP+\Delta O_j\}$. This offset value reflects a track pitch that enables the adverse effects of crosstalk to be suppressed. Accordingly, by positioning the head 12_{-i} at the determined target position TP and executing a read/write, it is possible to achieve a data track pitch DTP that enables the use of the disk 11 in which the servo tracks 111 are arranged at a fixed pitch (servo track pitch) STP, with the adverse effects of crosstalk suppressed.

In the above embodiment, the areas A_1 to A_n on the recording surfaces H_0 and H_1 of the disk 11 and

the offset values O_1 to O_n and ΔO_1 to ΔO_n for the respective areas A_1 to A_n are determined taking into account a difference in the azimuth angle of the heads 12_{-0} and 12_{-1} at each position on the disk in the radial direction, as well as a difference in head width between the heads 12_{-0} and 12_{-1}. However, only one of these two differences may be taken into account. For example, if only the difference in azimuth angle is taken into account, each of the recording surfaces H_0 and H_1 of the disk 11 may be similarly divided into a plurality of concentric areas. In this case, the adverse effects of the difference in head width between the heads 12_{-0} and 12_{-1} may remain. These adverse effects are eliminated by determining the offset values O_1 to O_n and ΔO_1 to ΔO_n on the basis of the upper limit value in the appropriate standard for the head widths of the heads 12_{-0} and 12_{-1}.

If only the difference in head width between the heads 12_{-0} and 12_{-1} is taken into account, the entire recording surfaces H_0 and H_1 of the disk 11 may correspond to the areas A_0 and A_1, respectively. Here, the offset values O_i and ΔO_i (or ΔO_i) may be set for each recording surface H_i (i=0, 1). The offset values O_i and ΔO_i can be determined (calculated) from the head width of the head 12_{-i} by measuring the head width during the manufacture of the

HDD (or the head 12_{-i}). The offset values O_i and ΔO_i (or ΔO_i) determined may be stored in the FROM 22, for example, in a format similar to that for the offset table 222, shown in FIG. 4. Here, information indicative of the recording surface H_i (head 12_{-i}) can be used in place of information (track position information indicative of the leading track) on the area A_i paired with the offset values O_i and ΔO_i (or ΔO_i). In this example, the number of entries in the offset table 222 can be sharply reduced. However, the adverse effects of the difference in the azimuth angle at each position on the disk in its radial direction between the heads 12_{-i} may remain. These adverse effects are eliminated by determining the offset values O_1 to O_n and ΔO_1 to ΔO_n on the basis of the upper limit value in the appropriate standard for the head widths of the heads 12_{-0} and 12_{-1}.

Furthermore, if only the difference in head width is taken into account, the heads are classified into, for example, first heads having a head width meeting a first standard and second heads having a head width which is outside the first standard but which meets a second standard. This classification serves to provide HDDs such as those described below. First, the upper limit value of the head width in the first standard is defined as HW_{UL1}. The upper limit value of the head width in the second standard is defined as

HW_{UL2} ($HW_{UL2}>HW_{UL1}$). Then, the heads are classified into the first heads having a head width meeting the first standard, the second heads having a head width which is outside the first standard but which meets the second standard, and third heads having a head width that is also outside the second standard. The third heads are treated as defectives that cannot be mounted in HDDs. On the other hand, the first heads are mounted in a first HDD that realizes a first data track pitch DTP (first track density). The second heads are mounted in a second HDD that realizes a second data track pitch DTP (second track density) larger than the first data track pitch DTP (first track density). The offset value O_1 ($=\Delta O_1/2$) determined from the head width HW_{UL1} is stored in a predetermined position in the FROM 22 in the first HDD, as shown in FIG. 8A. The offset value O_1 is stored in the FROM 22 in the first HDD while this HDD is being manufactured. On the other hand, the offset value O_2 ($=\Delta O_2/2$) determined from the head width HW_{UL2} is stored in a predetermined position in the FROM 22 in the second HDD, as shown in FIG. 8B. The offset value O_2 is stored in the FROM 22 in the second HDD while this HDD is being manufactured. The relationship between the offset values O_1 and O_2 is $O_1<O_2$. Consequently, the use of the second head enables the second HDD to be manufactured in spite of

a decrease in track density compared to the first HDD manufactured using the first head. That is, it is possible to effectively utilize the second head, having a head width which is outside the first standard but which meets the second standard.

Now, a process of determining the offset values O_j and ΔO_j for each area A_j will be described with reference to the flow charts in FIGS. 9A and 9B and FIGS. 10A, 10B, and 10C showing the head position. Here, for simplification of description, it is assumed that the entire recording surfaces H_0 and H_1 of the disk 11 are divided into a number n of areas A_j, i.e. A_1 to A_n for management. First, the CPU 21 sets a pointer j specifying the area A_j, at an initial value of 1 and sets a variable h for determining the offset value, at an initial value of 1 (step S11). Then, the CPU 21 selects the track (servo track) T_{jk} from the area A_j on the disk 11 (step S12). Here, it is assumed that the track T_{jk} is one of the servo tracks 111 in the area A_j which lies at an intermediate position in the radial direction of the disk. However, the track T_{jk} may be located at another position in the area A_j.

Then, the CPU 21 executes control to position the head 12_{-i} corresponding to the recording surface H_i on which the area A_j exists, at a predetermined position on the track T_{jk} (step S13). In step S13, the CPU 21

executes seek control to move the head 12_{-i} to the track T_{jk}. The CPU 21 also executes positioning control to position the head 12_{-i} moved to the track T_{jk}, at a predetermined position on the track T_{jk}. FIG. 10A shows that the head 12_{-i} is positioned at the predetermined position on the track T_{jk}. In the state shown in FIG. 10A, the CPU 21 causes the head 12_{-i} to write one track (for example, 512 sectors) of first test data to the disk 11 (step S14). Then, the CPU 21 causes the head 12_{-i} to read data from the track T_{jk} and measures an error rate ER_1 indicative of the rate of a read error (step S15). The measured error rate ER_1 is stored in a first area in the RAM 23.

Then, the CPU 21 executes control to shift the position of the head 12_{-i} from the track T_{jk} (the predetermined position on the track T_{jk}) in a radially outward direction of the disk 11 by the amount STP+(h-1)*ΔO (step S16). FIG. 11B shows that the position of the head 12_{-i} has been shifted from the track T_{jk} in the radially outward direction of the disk 11 by the amount STP+(h-1)*ΔO. For h=1, the value of the offset of the head 12_{-i} from the track T_{jk} equals the STP (Servo Track Pitch). In the state shown in FIG. 11B, the CPU 21 causes the head 12_{-i} to write one track of second test data to the disk 11 (step S17). Then, the CPU 21 executes control to shift the position of the head 12_{-i} from the track T_{jk}

(the predetermined position on the track T_{jk}) in a radially inward direction of the disk 11 by the amount STP+(h−1)*ΔO (step S18). FIG. 11C shows that the position of the head 12_{-i} has been shifted from the track T_{jk} in the radially inward direction of the disk 11 by the amount STP+(h−1)*ΔO. This position of the head 12_{-i} is offset from the position shown in FIG. 11B by the amount 2{STP+(h−1)*ΔO}.

In the state shown in FIG. 11C, the CPU 21 causes the head 12_{-i} to write one track of second test data to the disk (step S19). Then, the CPU 21 executes control to return the head 12_{-i} to the position of the track T_{jk} (step S20). The CPU 21 causes the head 12_{-i} to read data from the track T_{jk} and measures an error rate ER_2 indicative of the rate of a read error (step S21). The measured error rate ER_2 is stored in a second area in the RAM 23. Then, on the basis of the error rates ER_1 and ER_2 stored in the first and second areas, respectively, in the RAM 23, the CPU 21 makes determinations described below. The CPU determines whether or not the value ER_2-ER_1 is smaller than a threshold TH (step S22).

Here, it is assumed that ER_2-ER_1≥TH. In this case, the CPU 21 determines that the writes of the second test data in steps S17 and S19 adversely affects the first test data written in the track T_{jk}. That is, the CPU 21 determines that the adverse

effects of crosstalk cannot be eliminated even by writing data while shifting the head 12_{-i} from the track T_{jk} in the radially outward or inward direction of the disk 11 by the amount $STP+(h-1)*\Delta O$. Then, the CPU 21 executes step S23, described later, in order to suppress the adverse effects of crosstalk. Specifically, the CPU 21 increments a variable h by 1 in order to increase the value of the offset of the head 12_{-i} from the track T_{jk} (step S23). Then, the CPU 21 uses the incremented variable h to execute steps S14 to S22, described later. That is, the CPU 21 repeats steps S14 to S22 while incrementing the variable h by 1 until $ER_2-ER_1<TH$ (step S23).

It is assumed that $ER_2-ER_1<TH$. In this case, the CPU 21 determines that the current value of the offset of the head 12_{-i} from the track T_{jk} is the minimum offset value required to eliminate the adverse effects of crosstalk. Then, the CPU 21 determines whether or not the pointer j is 1 (initial value) (step S24). If the pointer j is 1, the CPU 21 determines the offset values ΔO_j and O_j unique to the area A_j in accordance with the following equation (step S25):

$$\Delta O_j = 2(h-1)*\Delta O$$
$$O_j = \Delta O_j/2 \qquad (4)$$

On the other hand, if the pointer j is not 1, the CPU 21 determines the offset values ΔO_j and O_j unique to the area A_j in accordance with the following

equation (step S26):

$$\Delta O_j = 2(h-1) * \Delta O$$

$$O_j = O_{j-1} + \Delta O_{j-1}(N_{j-1} - 1/2) + \Delta O_j/2 \quad (5)$$

Then, the CPU 21 stores information indicative of the leading track T_{j0} in the area A_j and information indicative of the offset values O_j and ΔO_j determined, in the entry E_j in the offset table 222, retained in the FROM 22 (step S27). Then, the CPU 21 determines whether or not the pointer j is n, indicating the final area An (step S24). If the pointer j is not n, the CPU 21 increments the pointer j by one and sets the variable h at 1 (initial value) (step S29). Then, the CPU 21 executes the process starting with step S12 in order to determine the values ΔO_j and O_j unique to the area A_j indicated by the incremented pointer j. That is, the CPU 21 repeats the process starting with step S12 until the pointer j becomes n and the values ΔO_j and O_j unique to the area A_n are determined. Then, if it is determined at step S28 that the pointer j is n, the CPU 21 ends the process of determining the offsets O_j and ΔO_j.

In the above described process of determining the O_j and ΔO_j, for simplification of description, the process from steps S13 to S21 is executed only once for a certain h. However, for measurement accuracy, the process from steps S13 to S21 may be repeated

a predetermined number of times r. In this case, it may be determined whether or not the value $(\{\Sigma(ER_2)-\Sigma(ER_1)\}/r)$ is smaller than the threshold TH. The value $(\{\Sigma(ER_2)-\Sigma(ER_1)\}/r)$ is obtained by subtracting the average of error rates ER_1 $(\Sigma(ER_1)/r)$ from the average of error rates ER_2 $(\Sigma(ER_2)/r)$.

In the above embodiment, the heads 12_{-0} and 12_{-1} are each of a composite type. However, the heads 12_{-0} and 12_{-1} may each be of an inductive type that uses a common element to execute read/write. In this case, the head width of the heads 12_{-0} and 12_{-1} has only to be taken into account. The recording surfaces H_0 and H_1 of the disk 11 may be managed as areas A_0 and A_1, respectively.

In the description of the above embodiment, the present invention is applied to the HDD (Hard Disk Drive). However, the present invention is applicable to disk drives other than HDDs, such as magneto-optical disk drives provided that their heads read and write data from and to a disk.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as

defined by the appended claims and their equivalents.